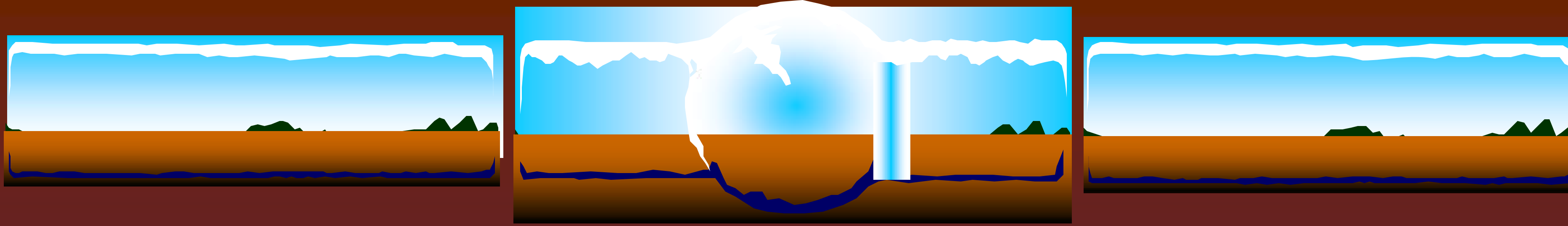

DOE's EGS Program Review

Chemical Stimulation of Engineered Geothermal Systems

DE-FG36-04GO14295

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Marriott Hotel
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Project Objective

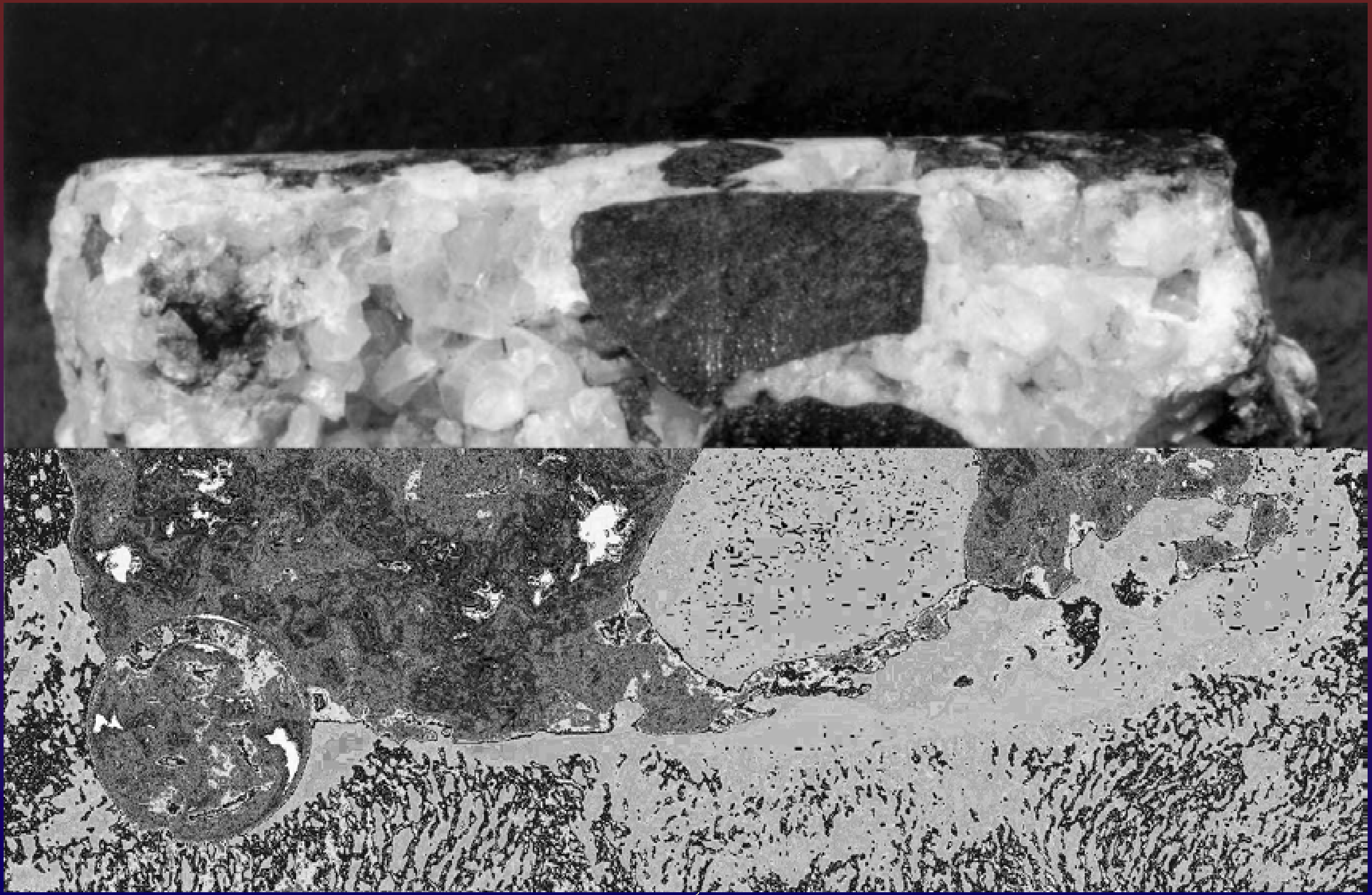
- To design, develop, and demonstrate methods for the chemical stimulation of candidate EGS reservoirs.

EGS Problem

- Why is project important to EGS program?
  - This project is important to the EGS program, since it will demonstrate an effective and affordable method for enhancing fracture permeability in EGS reservoirs.
- What technical issue does the project address?
  - The technical issue that the project addresses is the enhancing of fracture permeability. In many candidate EGS reservoirs, fracture networks exist but are occluded through mineral deposition. As these minerals are dissolved, fracture apertures increase and permeability is enhanced.
- How will project help to achieve overall program goals?
  - Accomplishment of the objectives of this project will assist DOE in meeting its interim objective of demonstrating the feasibility of creating EGS circulation systems at commercial production rates by 2010:
    - Increase EGS net output power of one production well from 1.4 MWe to 2.5-9.8 MWe by 2010
    - Double the mass flow rate of one well from 15 kg/sec to 30 kg/sec
    - Increase the effective fracture contact area from 0.56 to 0.6 km^2
    - Increase the short-circuiting index from 0.000011 to 0.0033

Background/Approach

Blocky Calcite within a Fracture from a Cored Well at Coso

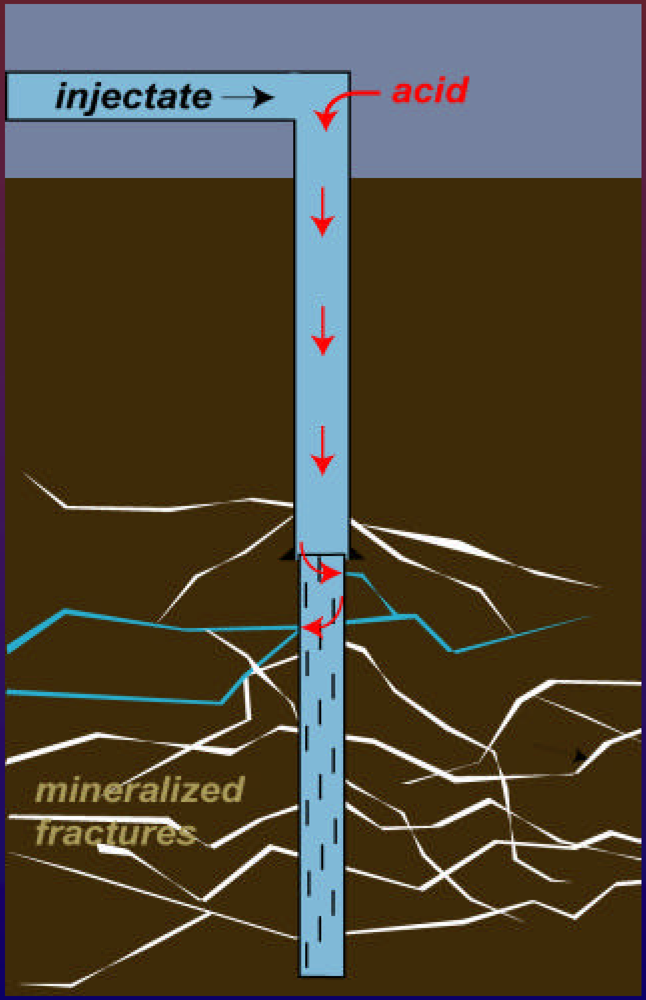


Chemical Stimulation in Petroleum Reservoirs

- ‘Acid fracturing’ was first used in the oil industry when acid was used to enhance the effects of hydraulic fracturing (Bradley et al, 1989)
- But wellbore treatments became problematical as temperatures increase, resulting in runaway and corrosive processes.
- Strong acids react so aggressively with calcites that above $0^{o}C$ they are diffusion limited (Lund, 1975)
- Strong acids react with carbonates by creating large flow channels (wormholes) within the near-wellbore formation that subsequently accept most of the acid-stimulation fluids (Fredd and Fogler, 1998a)

Mineral Dissolution in Geothermal Wellbores and in Near-Wellbore Formations Using Acids

- Strong acids are used in geothermal reservoirs to dissolve minerals in near-wellbore formations and to remove scale from wellbores, but by-passing is common and interactions with formation clays can be unpredictable, especially at high temperatures (P. Spielman, pers. comm.).
- Strong acids are deleterious to steel liners.



Weak Organic Acids as Alternatives to Strong Mineral Acids

- Weak organic acids above a pH of 3 proposed as alternatives for wellbore cleanup, especially in wells with temperatures in excess of 120^{o}C (Bradley et al, 1989; Fredd and Fogler, 1998b)
- Boles (1986) identified several aromatic acids that were stable at temperatures as high as 350^{o}C
- Adams et al (1992) identified 17 aromatic acids possessing excellent thermal stability

Chelants as Mineral Dissolution Agents

- Common chelating agents such as EDTA and HEDTA proven effective in dissolving carbonates at temperatures exceeding 200°C (Ali et al, 2002)
- Synergistic effects of chelation and acidity, since some chelants tolerate acidities below pH 4
- Some chelation formulations above a pH of about 12 required no inhibitor to achieve acceptable levels of corrosion at high temperature.

Approach

- Determine decay- and dissolution-kinetics of candidate compounds under simulated geothermal conditions
  - Steam condensate and other under-saturated fluids
  - Strong mineral acids with corrosion inhibition
  - Weak (organic) acids
  - Chelating agents
- Test most promising candidates in geothermal reservoirs
  - Borehole scale
  - Near-wellbore reservoir calcite
- Based upon laboratory and field experiments, develop models to predict the effects and costs of chemical stimulation in EGS settings

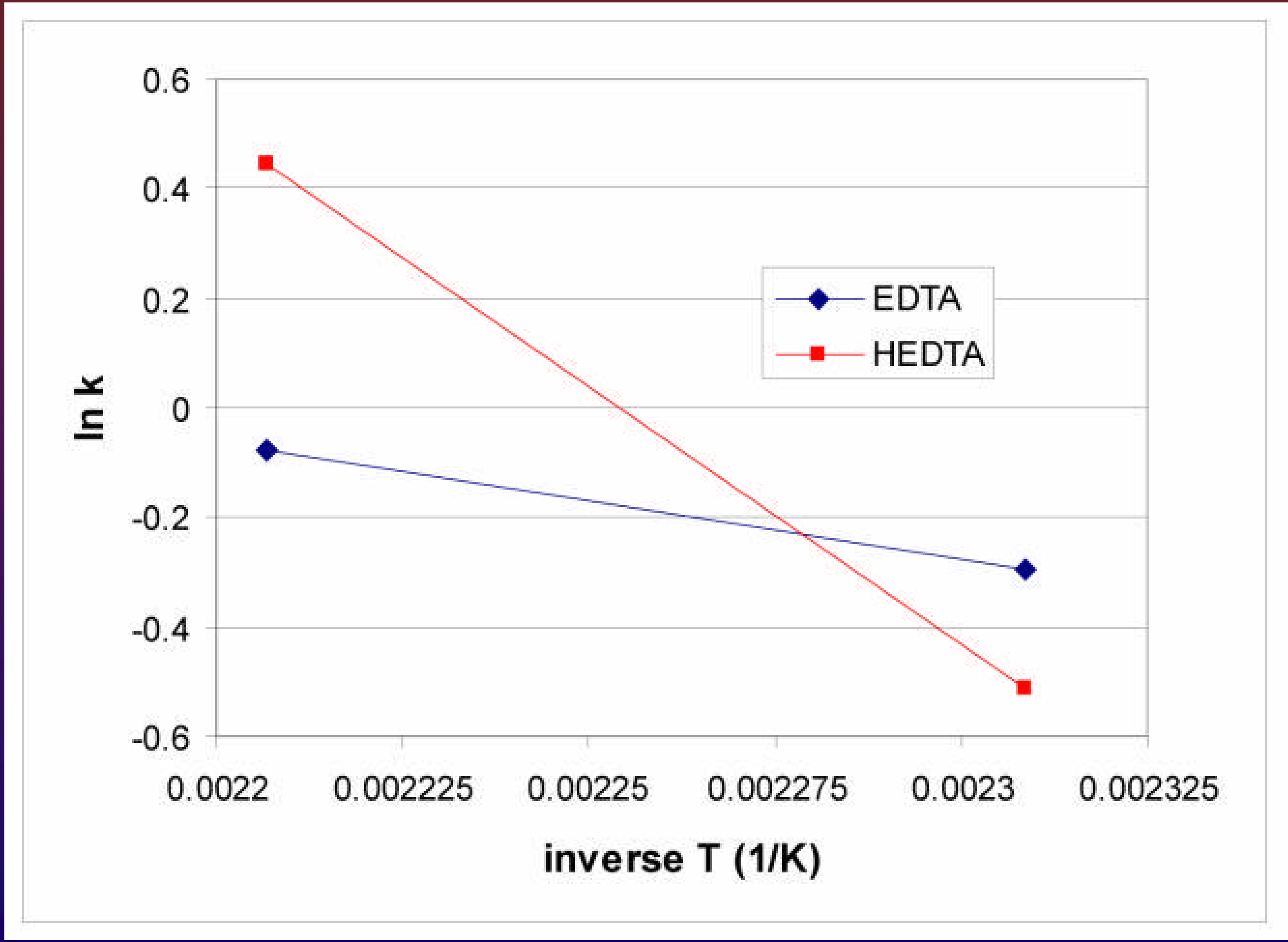
Results/Accomplishments

1. Laboratory Studies
2. Reactive Transport Modeling
3. Field Experiment

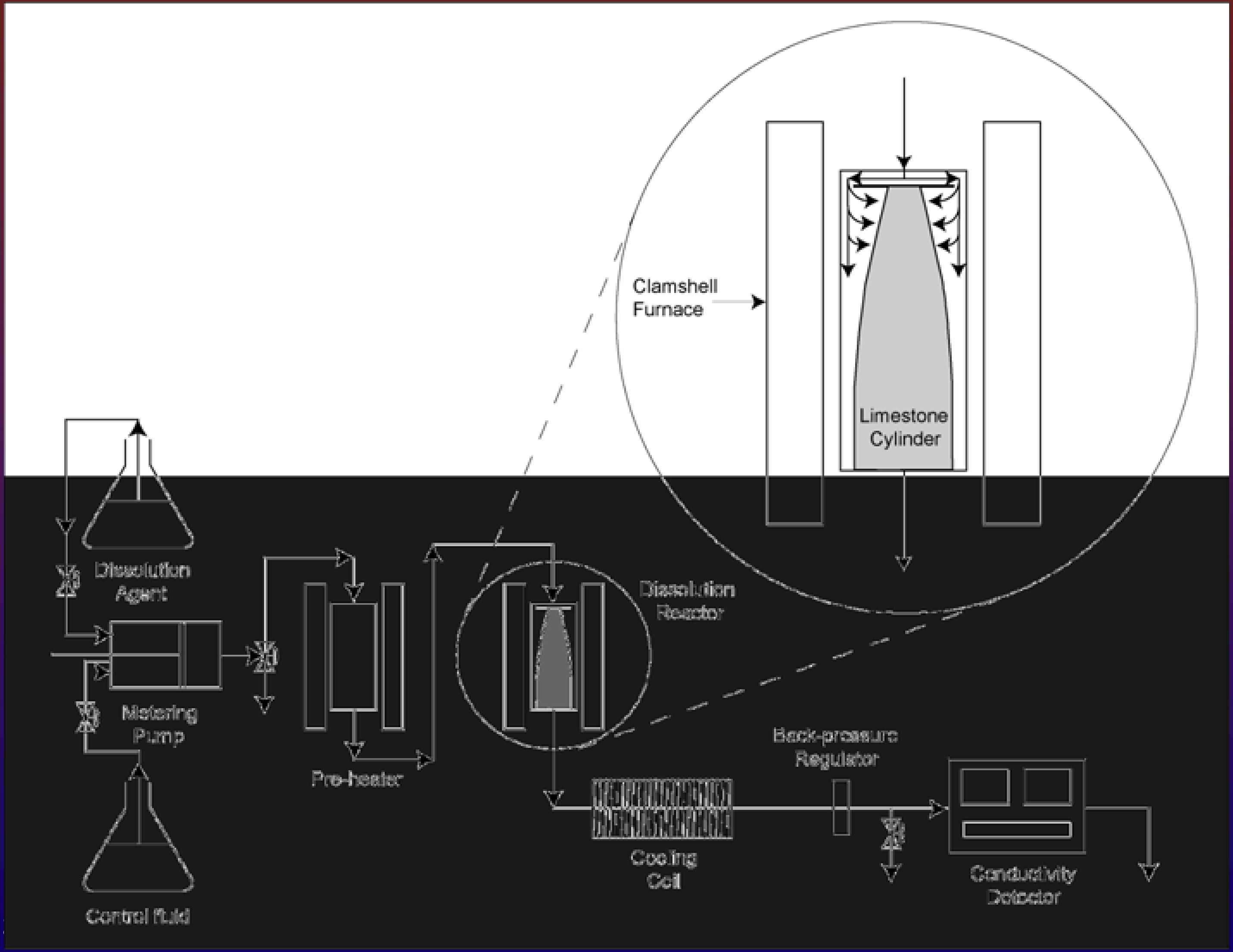
Analytical Methods and Thermal Stability Studies

Compound	Analytical Method	Maximum Use Temperature
Benzoic acid	HPLC/uv	275^{o}C
Acetic acid	--	350^{o}C
EDTA	HPLC/uv	200^{o}C
HEDTA	HPLC/uv	200^{o}C
NTA	HPLC/uv + derivatization	290^{o}C

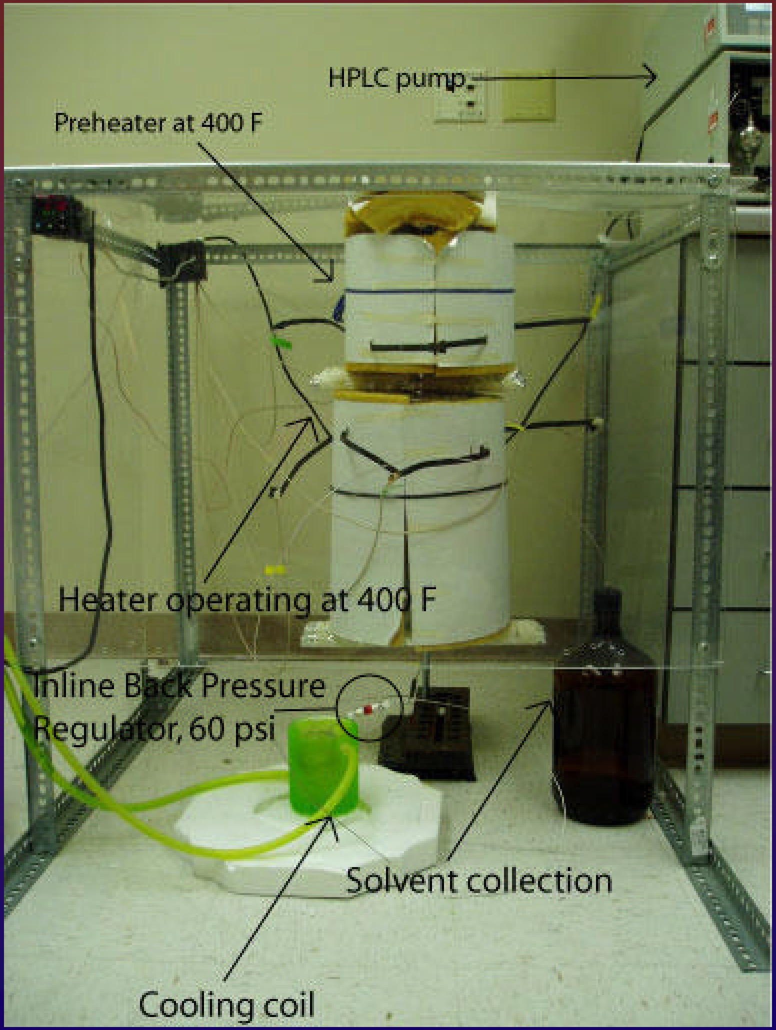
Arrhenius Plots for Thermal Decomposition of Chelating Agents under Geothermal Conditions



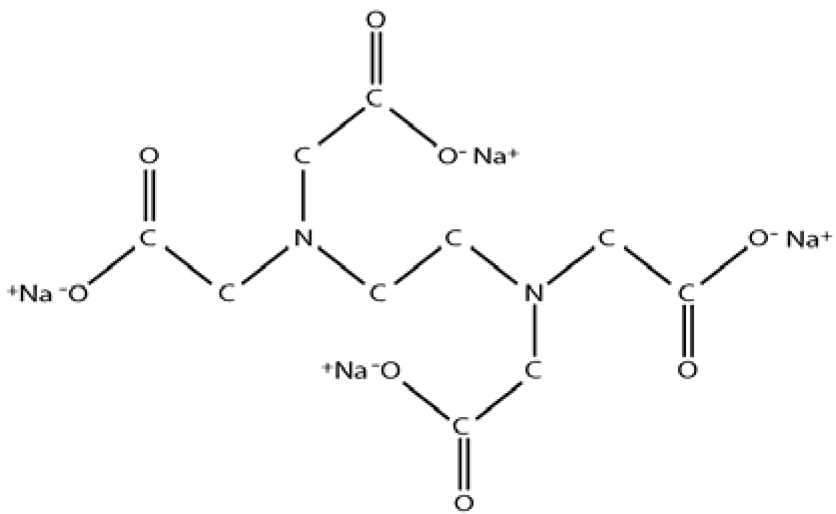
The Mineral-Dissolution Reactor



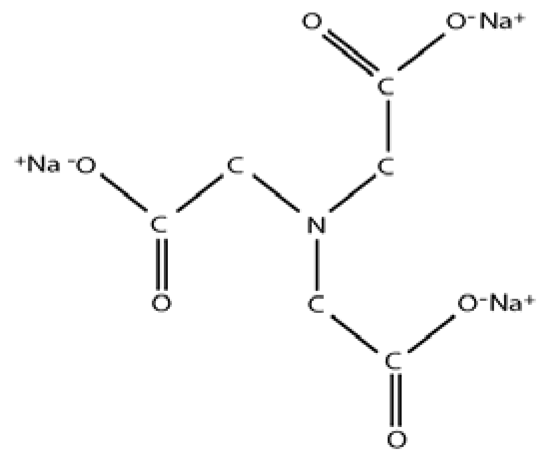
The Mineral-Dissolution Reactor



Chemical Structures of EDTA and NTA

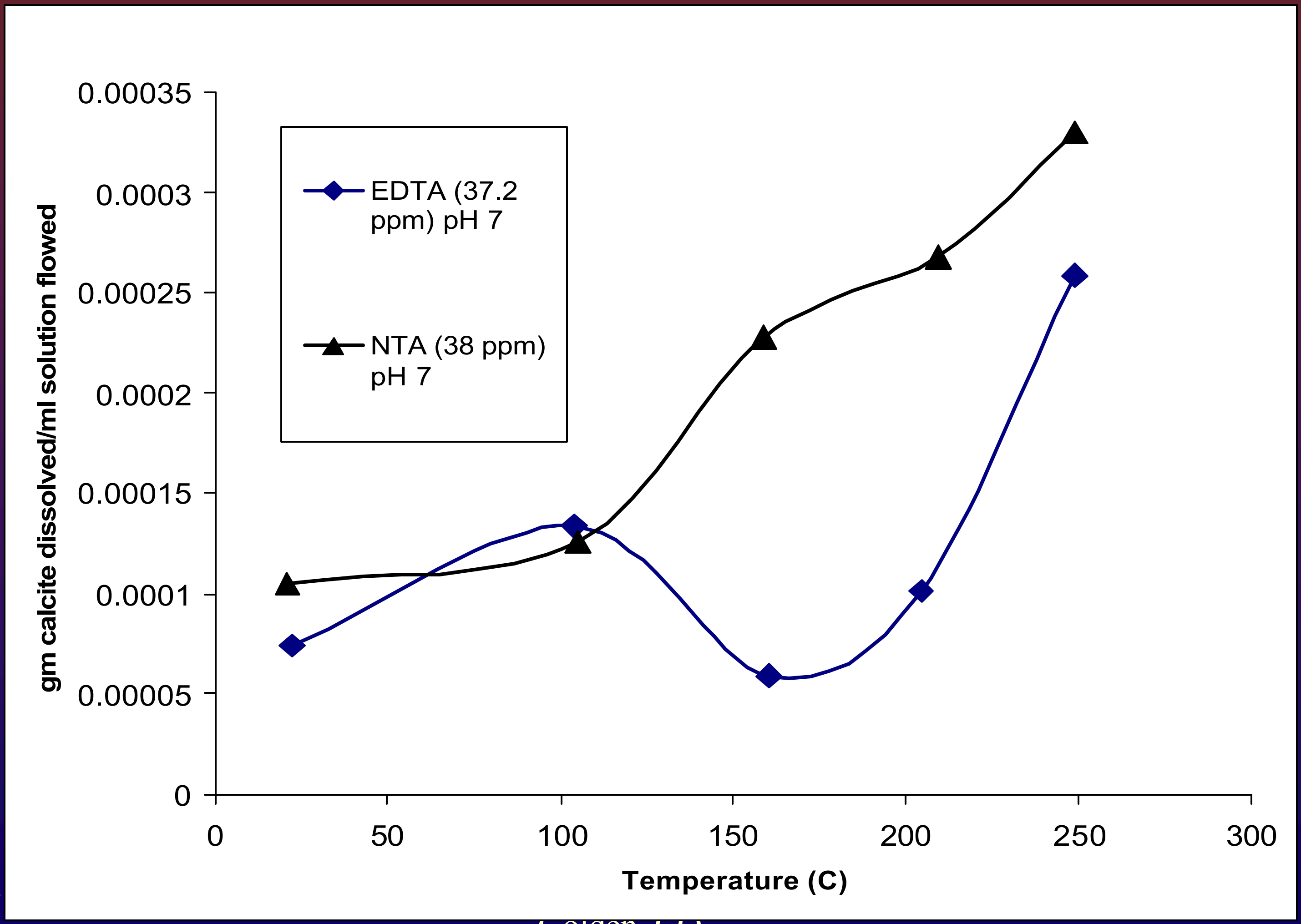


EDTA



NTA

Calcite Dissolution as a Function of Temperature for the Chelating Agents EDTA and NTA



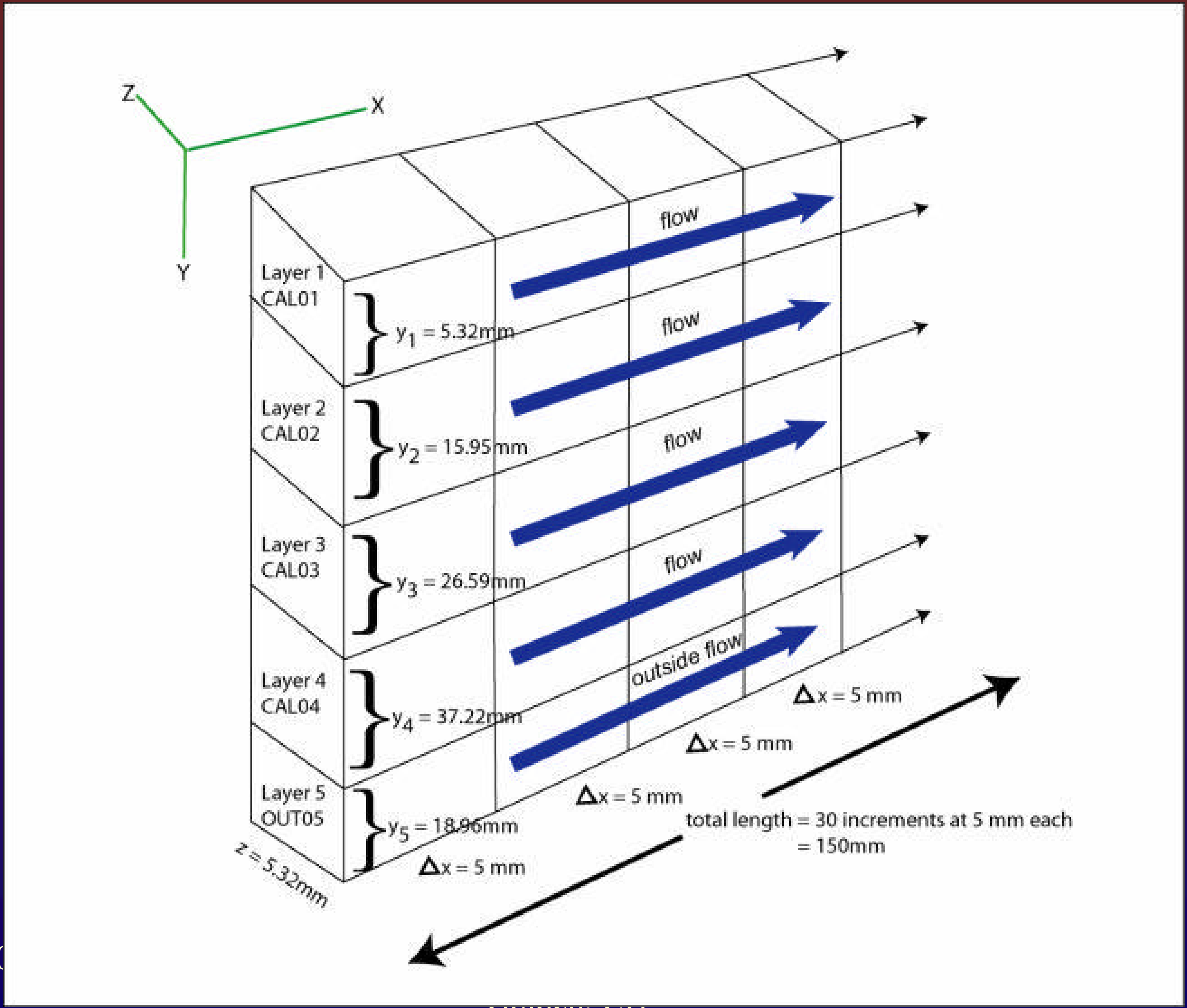
Modeling the Mineral Dissolution Process

Katie Kovac, Tianfu Xu, and Karsten Pruess

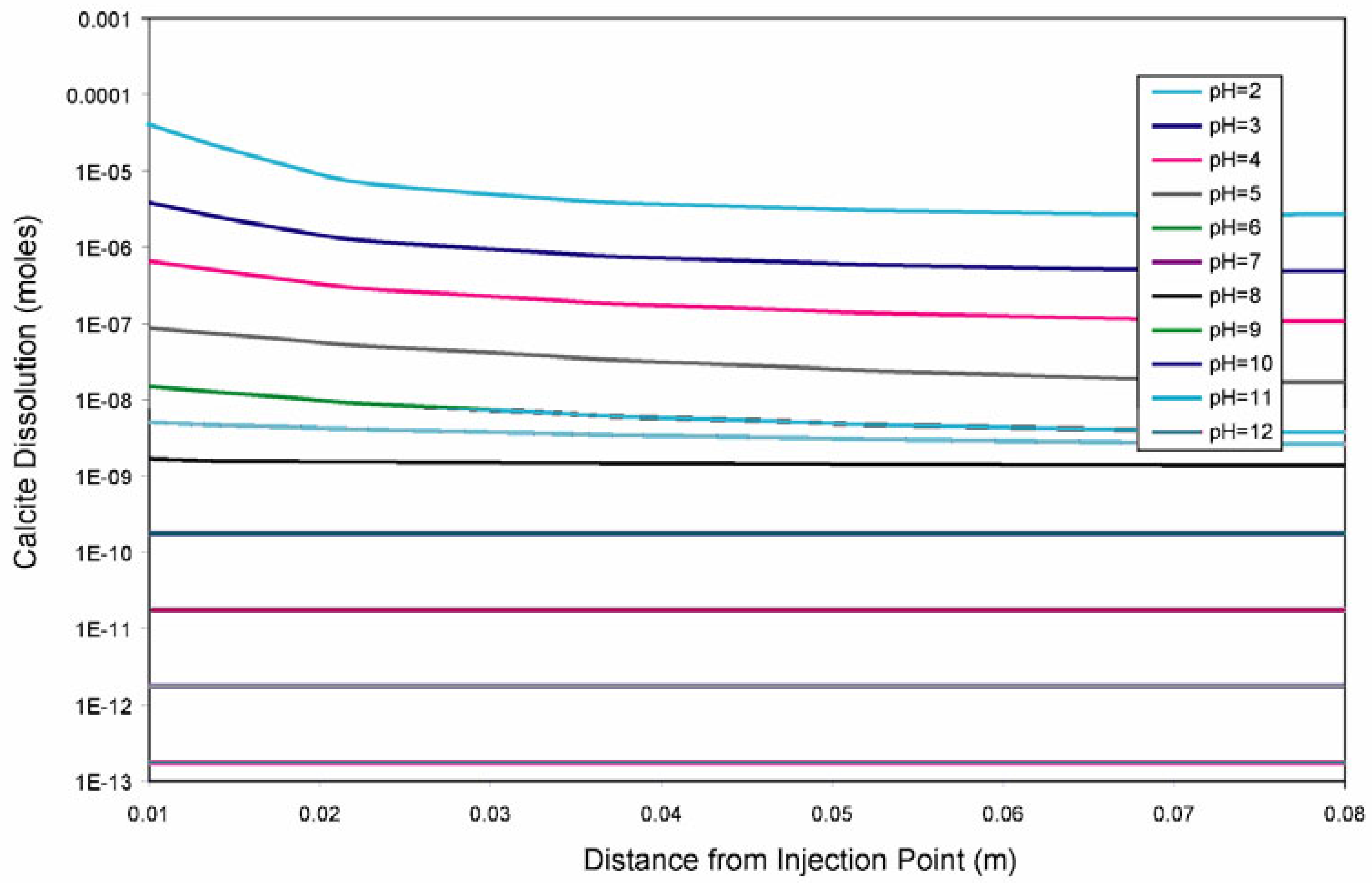
Approach:

- Construct a simple 1D TOUGHREACT model of the laboratory dissolution reactor to account for calcite dissolution and/or precipitation equilibria as functions of injectate properties.
- Incorporate thermal and dissolution kinetics of the most promising candidate into the model.
- Calibrate and update the model based upon laboratory data.
- Run and calibrate the model in simulation of a near-wellbore field experiment.
- Build a fullscale model to test the effectiveness and economics of chemical stimulation at reservoir scale.

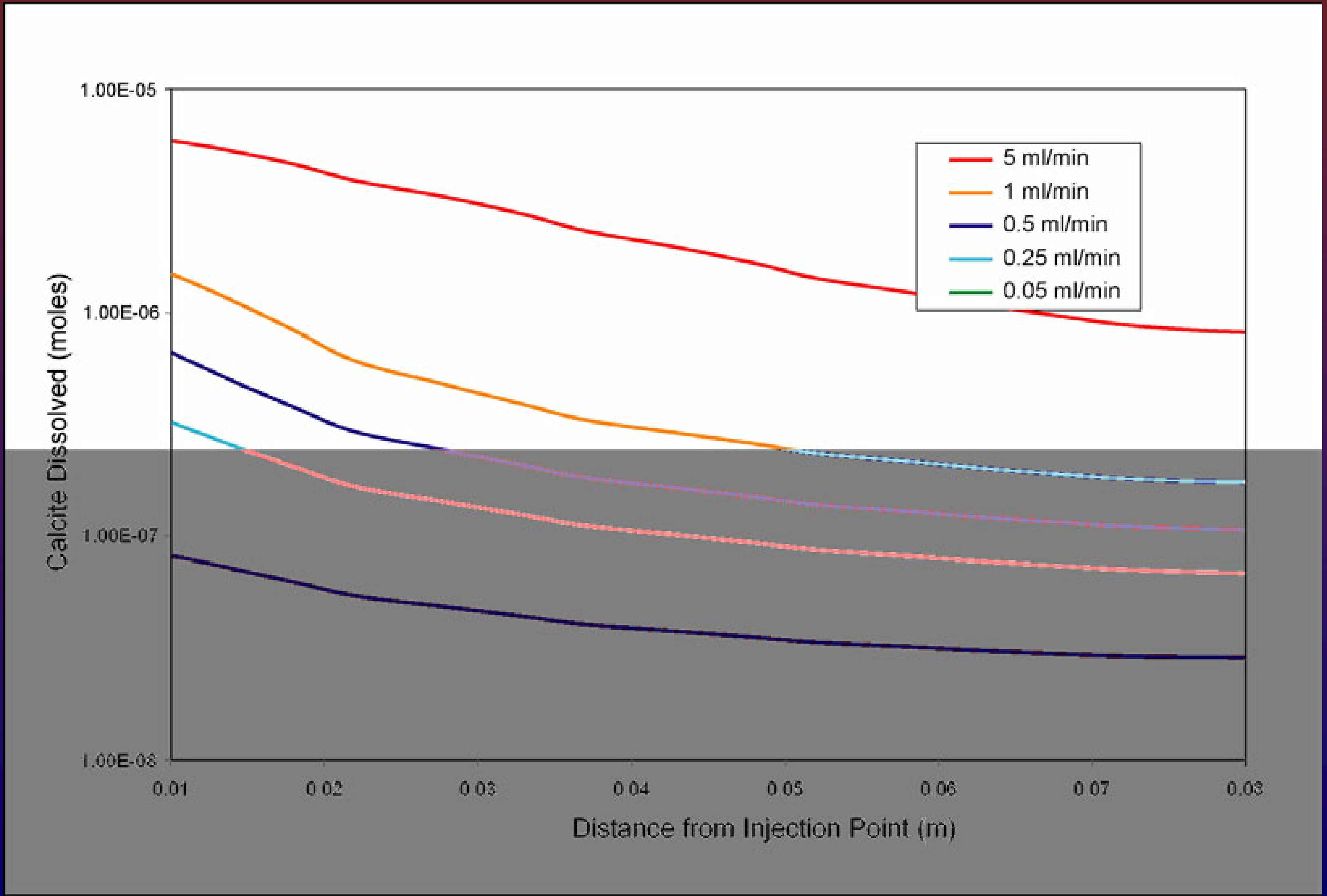
The Grid Used in the Laboratory Flow Reactor Model



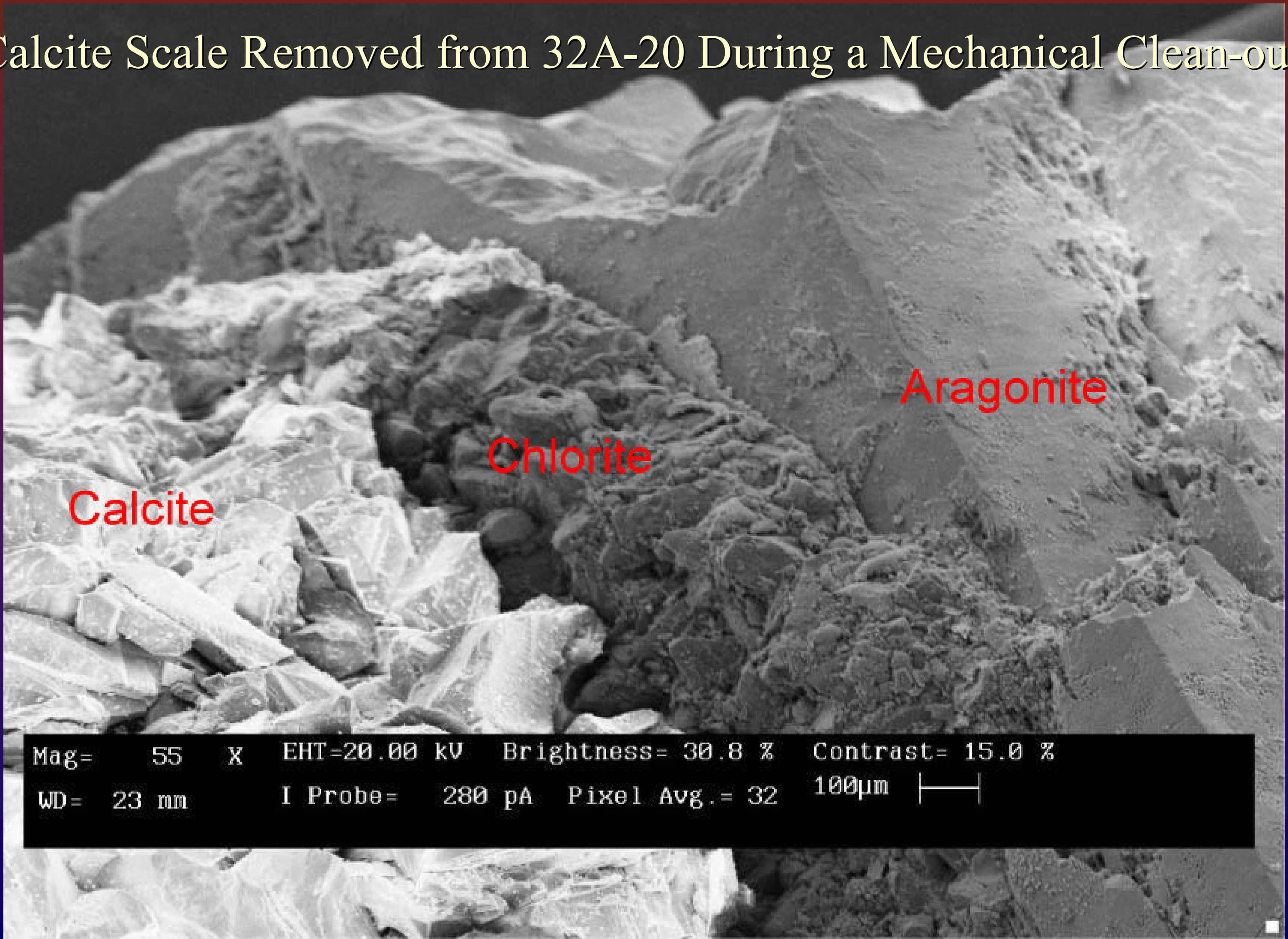
Simulated Calcite Dissolution Along Flow Reactor at Various pH's



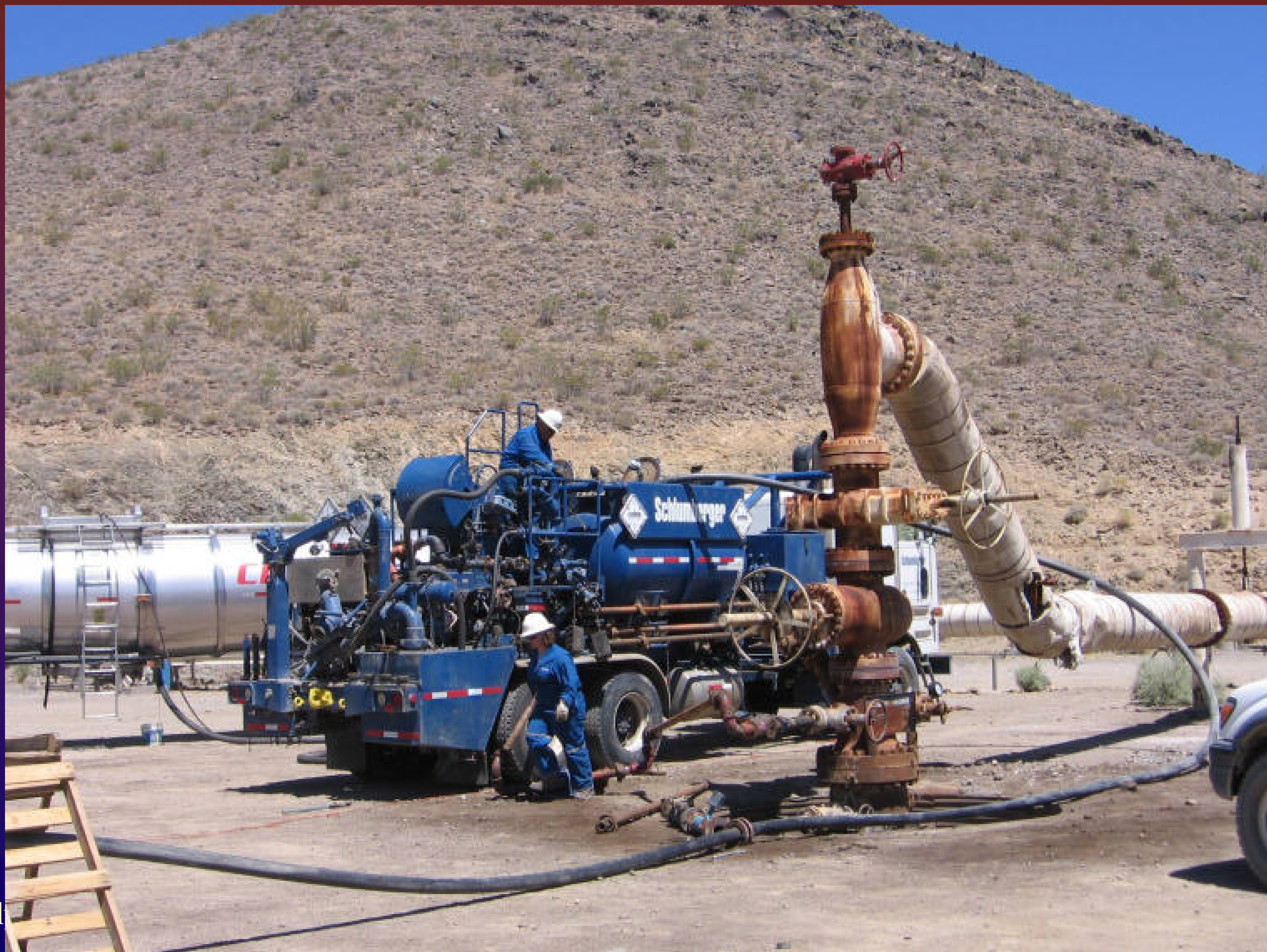
Simulated Calcite Dissolution Along Flow Reactor at Various Flow Rates



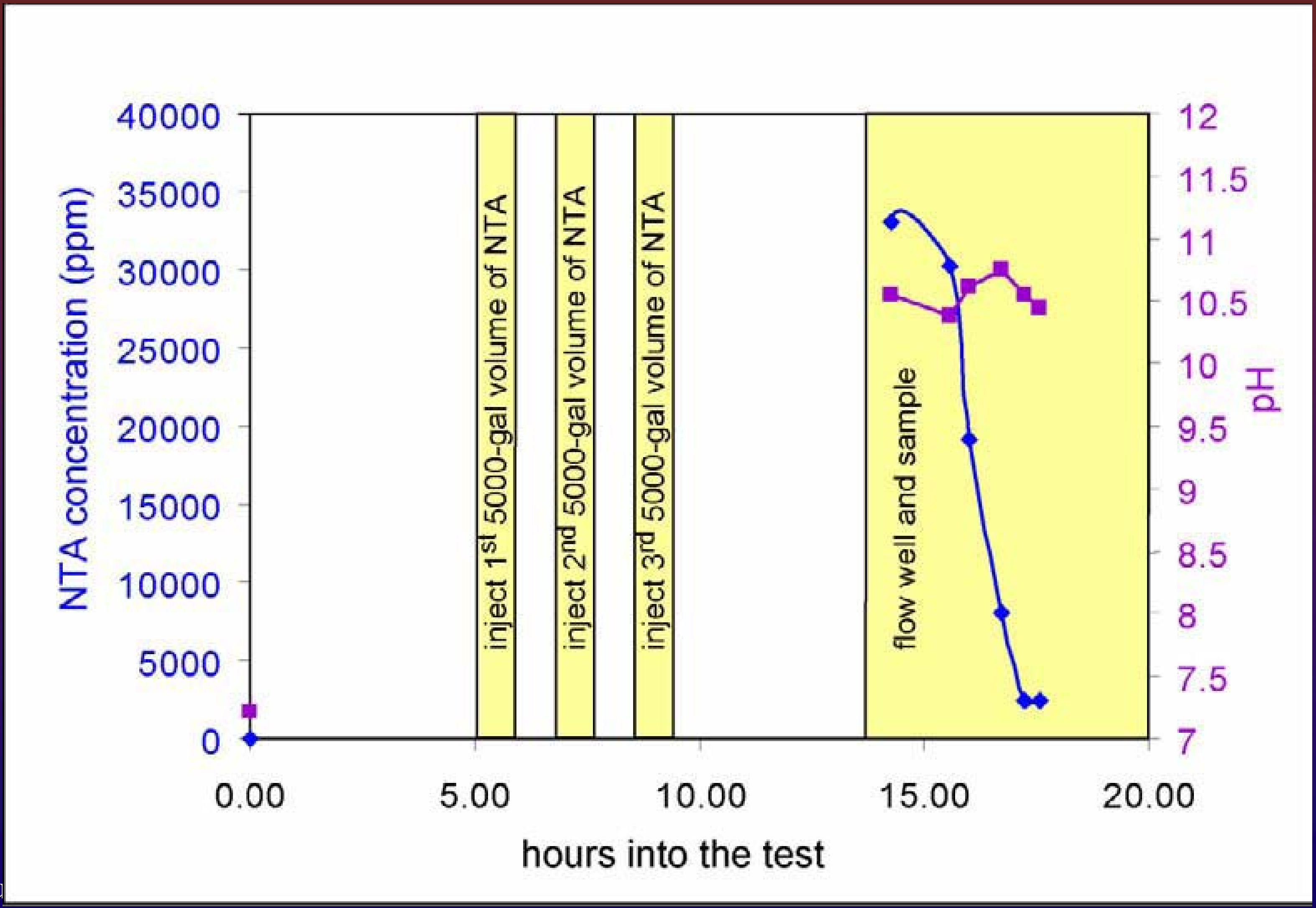
Calcite Scale Removed from 32A-20 During a Mechanical Clean-out



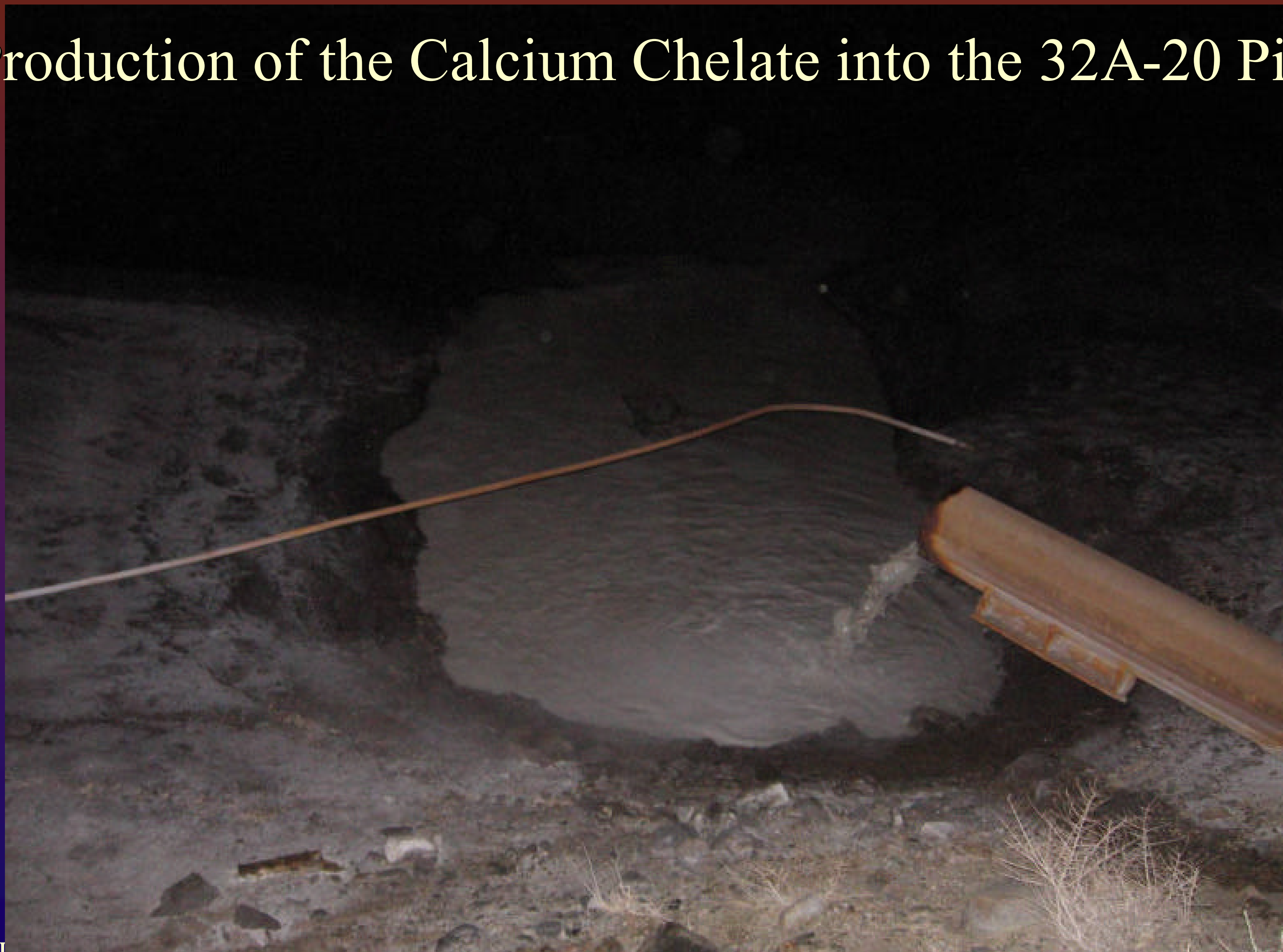
Injection of a Calcite Dissolution Agent into Coso Well 32A-20



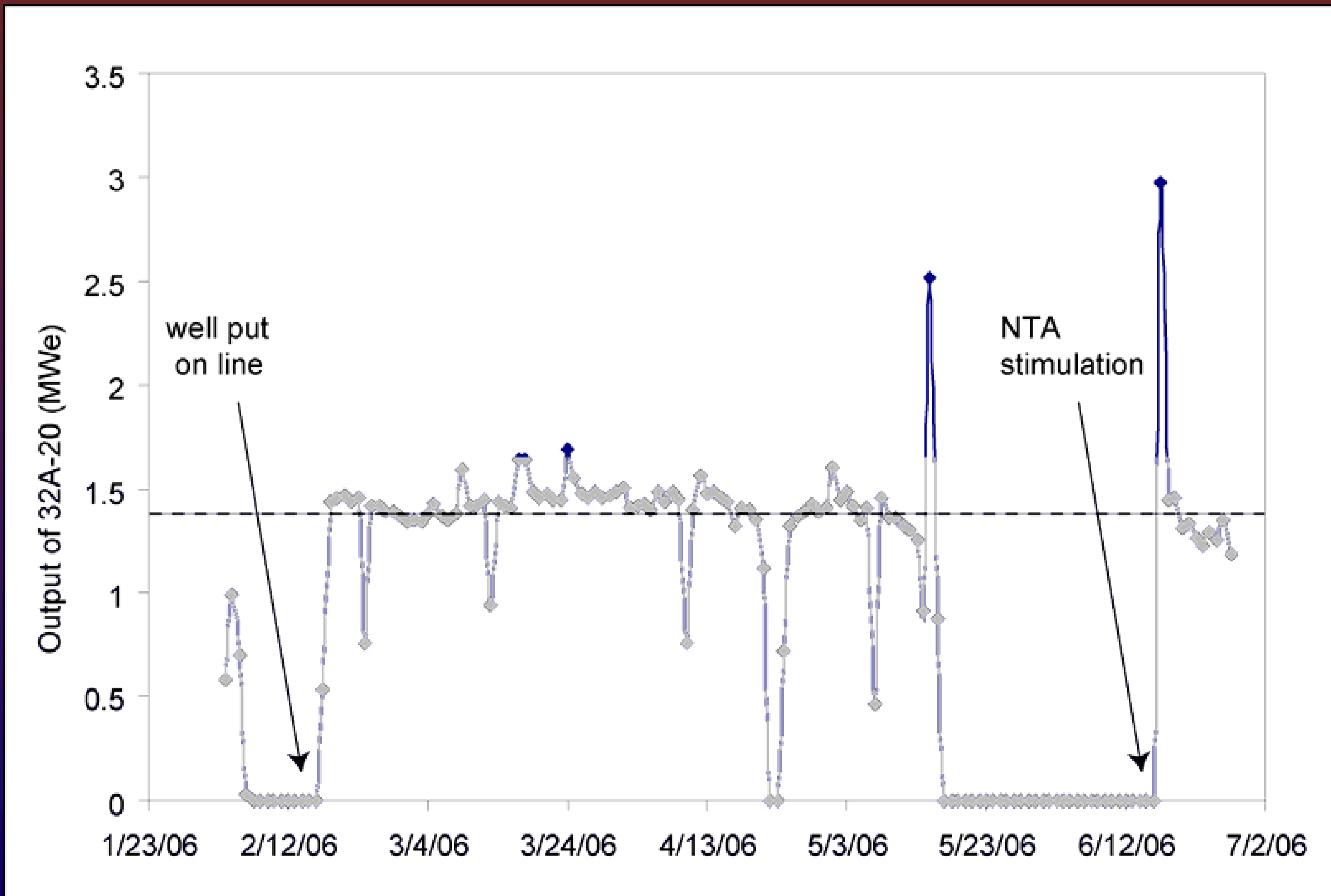
32A-20 Calcite Dissolution Experiment



Production of the Calcium Chelate into the 32A-20 Pit



Power Output from 32A-20



Quantity and Cost Comparison for Two Calcite-Dissolution Agents/Approaches

Calcite Dissolution Agent	Moles of Dissolution Agent Used	Effective Number of Moles Used	Corrosion Inhibitor Required?	Total Cost
NTA	20,100	30,200	no	$40,000
HCl in a "typical" acid job	667,000	667,000	yes	$100,000

Conclusion

- Will the project objective be achieved by the project completion date?
  - **Yes:** A cost effective mineral dissolution agent capable of reservoir stimulation was demonstrated in the laboratory and in a ***calcite***-scaled geothermal wellbore. It compares favorably to the state-of-the-art acid-treatment approach.
  - **No:** Further modeling and experimentation needs to be conducted in order to determine the economic feasibility of geothermal reservoir stimulation using mineral dissolution agents. Other organic acids and other chelating agents (e.g., the phosphonates) should be evaluated for their effectiveness as calcite dissolution agents. This project has also led to the development of a concept for the dissolution of ***silica*** (in the presence of ***calcite***) in the wellbore and near-wellbore formation with the possibility of reducing costs below comparable mud-acid treatments by a factor of 10. This concept should be tested.